International Journal of Physics and Research (IJPR)
ISSN(P): 2250-0030; ISSN(E): 2319-4499
Vol. 4, Issue 2, Apr 2014, 1-6

MONOCHROMATICTY AND MASSIVE PHOTON INTRODUCTION

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ABSTRACT

Our theory encompasses the wave-like and mass-like nature of radiation. The term coherence stands for the light which is capable of interference and in order to yield many interfering fringes, it must be assumed as very monochromatic. The Coherence length is the extent in space over which the wave is nicely sinusoidal so that it's phase can be predicted reliably. In this approach we have introduced a quantity called Dual frequency which arises due to the aforesaid dual nature of radiation. The Photon, namely the quanta of radiation, has been considered to be massive with the aid of a gedanken experiment of the dual theory for developing an intuition regarding the two types of nature of Radiation.

KEYWORDS: Description of Light, Mass Concept, Uncertainty Relation, Dual Frequency, Stability

INTRODUCTION

History of Light

In the latter half of seventeenth century Newton proposed the "Corpuscular theory" of [(1, 10)] light, assuming light consists of tiny billiard ball like particles which are given out by luminous light. The wave theory of light was put forward by Huygens considering that a luminous object sends out disturbances in the form of waves, explaining reflection and refraction of light which was later decisively proved by Thomas Young and Fresnel to be correct and explain the phenomena of interference and diffraction. Fresnel treated light wave as transverse to explain Polarization of light waves. Huygens also assumed the existence of a hypothetical medium ether, through which light wave could pass. Maxwell's theory of light as electromagnetic waves was one of the greatest achievements of the 19th century which rejected the idea of ether concerning no material medium for propagation. Maxwell's theory of light could explain rectilinear propagation, reflection, refraction etc. in addition to the phenomena like interference, diffraction and polarization.

The history of the photon in the 20th century started in 1901 when the eminent physicist Planck [(2)] put forward the formula for radiation of a black body and introduction of what was called later the quantum of action 'h' (Planck's constant). The electro-magnetic theory failed to explain several phenomena like black body radiation, origin of line spectrum, photo-electric effect, Compton Effect etc, relating about the emission and absorption of light. In 1902 Lenard [(3)] illustrate that energy of electrons in photoelectric effect is independent of the intensity of light, but depends on the wavelength of the latter.

In the year 1905 Einstein published fundamental article "On an Heuristic Point Of View Concerning the Production and Transmission of light" [(4), (5)] to make the globe astonished. Here he demonstrates that energy of light is distributed in space not uniformly, but in a form of localized light quanta. Einstein's light quanta behave as particles, it's carrying both the energy as well as momentum, was given in 1923 in the experiments by Compton [(6)] on Scattering of

X-rays on electrons. The term ‘photon’ for particles of light was given by Lewis in 1926 in an article “The Conservation of Photons” considering photons to be “atoms” of interaction.

A few years later eminent Physicist Dirac opened a new chapter in Physics by establishing Quantum Electrodynamics. So many questions arise” is Photon carrying mass”?

INTRODUCTION TO PHOTON MASS

Professor Albert Einstein (1905’s) energy-momentum dispersion relation, namely:

$$E^2=p^2c^2+m_oc^2 \quad (1)$$

Where E is the total energy of the particle, |p|=p is this particle’s momentum, m_0 is this same particle’s rest mass and c=2.99792458x10^8 m/sec is the speed of light in vacuum. The second fact is that the energy of the photon has been found from experience to be given by:

$$E=pc. \quad (2)$$

Now, neutrinos appear to travel at the speed of light and on account of the ‘Special Theory of Relativity’, they must be massless. Massless neutrinos have a problem to describe the phenomenon of Neutrino oscillations because this requires massive Neutrinos as described by Fermi and his Research Scholar Ettore Majorana.

Now if both the two equations (1) and (2) holds to the photon [(7)] having all the symbols remain unchanged with all the identical symbols, then it follows exactly that m_0, i.e. the rest mass of the photon must be zero

The assumption leading to the fact that for photons m=0, so that energies (E) in the formulae $E^2=p^2c^2+m^2c^4$ and E=pc are identical.

If these two energies are different then equation (1) is the total gravitational energy E_g of the photon so that $E_g^2=P^2C^2+m_0^2C^4$ and kinetic energy E_k =Pc. so we can write

$$E_g^2=E_k^2+m_0^2C^4 \quad (3)$$

Based on this kind of thinking one question arise to verify about the mass of photons.

Photon is considered as the fundamental particle to mediate electromagnetic radiation, [(8)] conveying energy and momentum and propagates through the vacuum at the constant velocity ‘c’, In accordance with the second postulate of Einstein’s theory of special relativity Where it is stated that no speed should be greater than the speed of light in the vacuum. So no signal should be transmitted in the speed greater than this.

Even so, experimental efforts to improve the limits on the rest mass of the photon have arisen to challenge[(13)] contemporary accepted theories, and this has been happening since the time of Cavendish, if not earlier, and in any case well before the modern concept of the photon was introduced.

MONOCHROMATICITY

The *total relativistic energy* of a particle is given by

$$E = mc^2 \quad (1)$$

Where the symbols have their usual meanings. From this equation we can write

$$\Delta E = \Delta m.\ c^2 \tag{2}$$

According to *Heisenberg's uncertainty principle*, the uncertainties in energy (E) and time (t) are related as

$$\Delta E.\ \Delta t \geq \frac{\hbar}{2} \tag{3}$$

where $\hbar$ is the *reduced Planck's constant*. Therefore using equation (2) we have

$$\Longrightarrow \quad \Delta m.\ c^2.\ \Delta t \geq \frac{\hbar}{2}$$

$$\Longrightarrow \quad \Delta m.\ \Delta t \geq \frac{\hbar}{2c^2} \tag{4}$$

Again, the energy (E) and frequency (ν) are related as

$E = h\ \nu$, where 'h' is the *Planck's constant*.

$$\Longrightarrow E = h\frac{c}{\lambda}$$

$$\therefore |\Delta E| = h\ c\ \left|\frac{\Delta\lambda}{\lambda^2}\right|$$

Putting this in equation (3) we will obtain

$$\Delta\lambda.\ \Delta t \geq \frac{\hbar}{2}\ \frac{\lambda^2}{h\ c} \tag{5}$$

A wave is characterized by its frequency, wavelength, phase or group velocity, amplitude and intensity. Moreover, a wave spreads out and occupies a relatively large region of space. A particle is characterized by its mass (m), velocity (v_p), momentum (p), energy (E). Moreover a particle [(9)] occupies a definite position in space and hence is highly localized. Evidently the nature and properties of a wave and a particle are to a large extent conflicting. Because a wave is spread out in space and a particle is localized at a point in space.

But these dual properties of light or radiation was experimentally theoretically confirmed by French theoretical physicist Louis de Broglie, who suggested that like radiation, matter also possesses dual (particle like and wave like) properties.

Now, from the contradictory dual nature of radiation it is obvious that the relations (4) and (5) cannot be simultaneous. Therefore, we may rewrite them as:

$$\Delta m.\ \Delta t_1 \geq \frac{\hbar}{2c^2} \tag{6}$$

and $$\Delta\lambda.\ \Delta t_2 \geq \frac{\hbar}{2}\ \frac{\lambda^2}{h\ c} \tag{7}$$

The Compton Effect and the Photoelectric Effect substantiate the corpuscular nature of radiation, i.e. during collision with a particle; radiation itself behaves like a particle. Again, Schrodinger and De Broglie had shown that every particle has an associated wave nature. Now, the wave-like nature and the particle nature of an emission or radiation are contradictory to each other. Hence, if we consider the wavelength (λ) and the mass (m) as the representative criteria of the wave-like and particle-like nature, then the measurement of both at the same instant must give rise to an uncertainty.

The problem is very similar to that of trying to see both sides of a coin at the same instant.

Now, let us consider a certain gedanken experiment [(11)], where a light source emits a wave of photons, assumed to possess a finite mass (m). The experimental setup is of very high precision. The photons interact with the body of the light source, say 'B', at an instant t_1 and exhibit their particle-like nature. The measurement of the mass (m) of a particular photon at t_1 gives rise to an uncertainty in the mass, say Δm, and an uncertainty in the time of its measurement, say Δt_1. After the aforesaid interaction, the photons travel as a wave of a certain wavelength (λ) and at instant t_2 ($t_2 > t_1$) exhibit their wave-like nature. The measurement of the wavelength (λ) at t_2 gives rise to an uncertainty in the wavelength, say $\Delta\lambda$, and an uncertainty in the time of its measurement, say Δt_2.

In light of the aforementioned gedanken experiment, we may interpret the Δt_1 and Δt_2 in equations (6) and (7) respectively, as the instants when the mass-like and wave-like nature of radiation is detected.

We may write

$$\Delta t_2 - \Delta t_1 = \Delta T \tag{8}$$

which is the difference between the two uncertain measurements of the instants when the considered radiation manifests the mass-like and the wave-like nature.

Now, if the 'T' in equation (8) can be presumed to be the time period of the light wave under consideration, then we will have [(12)]

$$T = \frac{1}{\nu}$$

$$\therefore |\Delta T| = \left| \frac{\Delta\nu}{\nu^2} \right| \tag{9}$$

Which gives the uncertainty in the measurement of the time period (T), also given by equation (8).

Now, from (6) and (7) we can write

$$\Delta t_1 \geq \frac{\hbar}{2c^2\Delta m} \quad \text{and} \quad \Delta t_2 \geq \frac{\hbar}{2}\frac{\lambda^2}{h\, c\, \Delta\lambda}$$

which yields

$$\Delta t_2 - \Delta t_1 \geq \frac{\hbar}{2c^2\Delta m} \backsim \frac{\hbar}{2}\frac{\lambda^2}{h\, c\, \Delta\lambda}$$

$$\Longrightarrow \Delta t_2 - \Delta t_1 \geq \frac{\hbar}{2c}\left[\frac{\lambda^2}{h\,\Delta\lambda} - \frac{1}{\Delta m\, c}\right]$$

Using (8) and (9) we get

$$\frac{\Delta\nu}{\nu^2} \geq \frac{\hbar}{2c}\left[\frac{\lambda^2}{h\,\Delta\lambda} - \frac{1}{\Delta m\, c}\right]$$

$$\Longrightarrow \frac{\Delta\nu}{\nu} \geq \frac{\nu}{2\pi}\left[\frac{h}{c}\left\{\frac{\lambda^2}{h\,\Delta\lambda} - \frac{1}{\Delta m\, c}\right\}\right] \qquad (10)$$

Again in equation (10), the term inside the third bracket has the dimension of the inverse of frequency. Let us term this frequency as the *dual frequency*, the expression for which is given by

$$\nu_1 = \frac{c}{h\left\{\frac{\lambda^2}{h\,\Delta\lambda} - \frac{1}{\Delta m\, c}\right\}} \qquad (11)$$

$$\frac{\Delta\nu}{\nu} \geq \frac{\nu}{2\pi}\cdot\frac{1}{\nu_1} \qquad (12)$$

From equation (11) we can observe that the *dual frequency* (ν_1) has dependence of 'Δm' and '$\Delta\lambda$', which helps us to conclude without loss of any generality that 'ν_1' intrinsically depends on the wave-like (λ) and particle-like (m) character of radiation, which precisely exhibit the dual nature of radiation.

Now, the ratio $\frac{\Delta\nu}{\nu}$ is termed as the *stability of light* emitted by a light-source and it satisfies the *condition of monochromatic nature of light* [(12)] given by

$$\tau_c = \frac{1}{\Delta\nu}$$

Thus, if we consider a light-source emitting radiation which proceeds along with the coherent exhibition of the dual character of radiation, then the *stability of light* and consequently its *monochromatic nature* can be attributed to the dual nature of radiation.

Therefore, if this dual nature of radiation is taken into consideration then we may be able to find out, with favorable experimental setup, as to what extent a light-source can be monochromatic, by the well-precision measurement of the *dual frequency*

$$\nu_1 = \frac{c}{h\left\{\frac{\lambda^2}{h\,\Delta\lambda} - \frac{1}{\Delta m\, c}\right\}}$$

CONCLUSIONS

From equation (10) it can be said that if Δm = 0, then $\frac{\Delta\nu}{\nu} \geq \infty$ and consequently $\Delta\nu \geq \infty$, which is not possible since the bandwidth of any light source cannot be infinite. Thus it can be concluded that the 'photon' has a finite

mass. This hideous 'photon-mass' is not detectable in low energy experiments, but may come into existence in case of high-energy experiments.

Other than that, with the advent of *string theory* as an ultimate theory towards the understanding of our universe, it might be possible to determine hidden dimensions in which the photon's mass is trapped and remains undetected due to low-energy experiments. But currently various benchmarks have been established regarding high-energy experiments such as the detection of the *Higgs-boson*, almost 50 years after its prediction. Thus with the resource of high-energy experiments it might be possible to determine more accurate values of the upper limit of photon mass and ultimately the true value of a non-zero photon mass.

REFERENCES

1. Photon: history, Mass, Charge: L. B Okun vol.37 (2006) act a physica Polonia B No
2. M. Planck, Ann. Phys. 4,561 (1901)
3. P. Lenard, Ann. Phys. 8, 169 (1902)
4. Einstein, Ann. Phys.17, 132 (1905)
5. "On the Heuristic point of view Concerning the production and Transmission of light"- Albert Einstein.
6. G.N Lewis, Nature, No. 2981. Volume. 118 (December 18, 1928) 874.
7. Are Photons Massless or Massive?: G.G NYAMBUYA vixra: 1301.oo61
8. On the gravitational Bending of Light. G.G NYAMBUYA.
9. A Text Book of Physics (2012) Calcutta Book House (P) LTD.
10. On the massive nature of Photon. Arka Dev Roy, INTERNATIONAL JOURNAL OF SCIENTIFIC & ENGINEERING RESEARCH, VOLUME 5, ISSUE 3,
11. Sorensen, R.A., Thought Experiments, Oxford University Press, (Oxford), 1992.
12. Ghatak, Ajoy. Optics, Tata McGraw-Hill, 4th ed., Delhi, 2010.
13. The Mass of the Photon: Reports on Progress in Physics, Liang-Cheng Tu, Jun Lou and George T Gillies.